

APPLICATION OF SURFACTANT SPRAY IN FLOTATION DEINKING

Project E010

Report 1

to the

MEMBER COMPANIES OF THE INSTITUTE OF PAPER SCIENCE AND TECHNOLOGY

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INSTITUTE OF PAPER SCIENCE AND TECHNOLOGY

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MEMBER COMPANIES OF THE INSTITUTE OF PAPER SCIENCE AND TECHNOLOGY

By

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March 1998

PROJECT OBJECTIVES:

The overall objective of the proposed research is to conduct a feasibility study of spray wash to control fiber loss, reduce consumption of surfactant, and maintain ink particle hydrophobicity in a laboratory flotation cell. The research includes the following tasks:

- (1) Design a laboratory batch type spray wash flotation deinking cell.
- (2) Study the effect of spray characteristics, droplet size distribution, momentum, and spray pattern on the ink particle removal efficiency.
- (3) Study the effect of spray wash on the selectivity of wash away fibers over ink particles.

MAIN RESULTS:

The research program was started in October 1997 with a fund of \$85,000. During the last 4 months, the proposed research program was tested using a laboratory flotation cell. The primary results indicated that the surfactant spray approach can reduce fiber loss by 50%, water loss by 75%, and surfactant consumption by 95% without sacrificing deinking efficiency. The proposed approach can also prevent fiber from contaminating of process surfactant. More importantly, this study developed a simple method to mechanically control froth stability when the physicochemical properties of the pulp source vary.

ABSTRACT

This report is concerned with increasing utilization of recycled fiber and, more specifically, with improving the ink removal efficiency; reducing the fiber loss, the water loss, the chemical consumption, and the contamination of fibers by processing chemicals. The research program was started in September 1997. One paper based on the results obtained in the last 4 months has prepared, and a patent has been filed.

In this report, the fundamental understanding of the flotation deinking process is first discussed, then experimentally study using innovative approach to control several key process variables that affect ink removal, froth stability, fluidynamics in froth, fiber contamination, fiber and water losses, and surfactant consumption are discribed. Instead of adding surfactant into the pulp slurry directly before flotation in the conventional process, a pressure atomizer was used to spray the surfactant solution from the top of the flotation column during flotation. Results indicated that the surfactant spray approach can reduce fiber loss by 50%, water loss by 75%, and surfactant consumption by 95% without sacrificing deinking efficiency. The proposed approach can also prevent fiber from contaminating of process surfactant. More importantly, this study developed a simple method to mechanically control froth stability when the physicochemical properties of the pulp source vary.

INTRODUCTION

Flotation deinking is a common practice for removing ink from wastepaper, and it is becoming a key process in many recycling paper mills. The application of flotation was successfully introduced to the paper recycling industry in the 1980s, and its applications in wax removal, sticky control, and fiber fractionation have attracted great research interest. The chemistry of the flotation process has been reviewed [1-3]. The deinking chemistry and the physicochemical interactions among air bubbles, fibers, and ink particles are very complex. Existing technologies and process designs of flotation deinking are based on experiences obtained from mineral flotation processes. Limited process control mechanisms are available. Many problems remain unsolved such as high fiber and water losses [4-9], fiber contamination by deinking chemicals, adverse chemistry modification due to surfactant [1,2,10,11], low efficiency in removal of small ink particles [12-14], etc. Therefore, innovative technologies based on the mechanistic understanding of flotation processes are greatly needed to solve or alleviate the above problems. Because of the significant variability in the supply of secondary fibers in recycling practices, process control in flotation deinking is very important to improve recycling operations.

UNDERSTANDING THE FLOTATION DEINKING PROCESS

Flotation deinking processes involve interactions among air bubbles, ink particles, and fibers. A successful flotation process typically has three major efficient subprocesses: detachment of the ink particles from waste fibers, effective adhesion of the ink particles onto air bubble surfaces, and removal of froth and ink particles from flotation cells.

The Roles of Surfactants

The roles of surfactants have been discussed in detail by Ferguson [1,2]. In general, surfactants play three roles in flotation deinking: as a dispersant to separate the ink particles from the fiber surface and prevent the redeposition of separated particles on fibers, as a collector to agglomerate small particles to large ones and change the surface of particles from hydrophilic to hydrophobic, and as a frother to

generate a foam layer at the top of the flotation cell for ink removal. Although surfactants play important roles, they will also cause some adverse effects on ink removal, fiber quality, and water reuse. For example, both hydrophobicity and ink removal efficiency will decrease by the adsorption of dispersant and frother [10,11]. The remaining surfactant in recycled fibers is another problem that may cause a decrease in fiber-fiber bonding, an increase in foams during the papermaking process, an adverse effect on printing, etc. Because surfactants have both positive and negative effects, it is of interest whether dispersant, collector, and frother can be separately controlled.

The surfactants used in mineral flotation may not be necessary in flotation deinking. For instance, some ink particles, such as xerox toner, are hydrophobic in nature and no collector is necessary. The dispersant may also be unnecessary if the ink particles can be removed from fibers by other chemicals, such as sodium silicate, sodium hydroxide and enzyme, or by mechanical actions, such as magnetic and electrical fields, and ultrasonic irradiation. Although dispersant and collector may not be necessary for some pulps, a frother has to be used in order to obtain a stable foam layer for removing ink particles. Traditionally, the frother and other surfactants are added in to the pulp suspension during pulping. However, the surfactant presented in pulp slurry will not only contribute to the foam stabilization, but also adsorb onto ink particle surfaces and cause a decrease in the hydrophobicity of ink particles. Furthermore, the mechanical control of froth stability is very difficult if the surfactant is directly added into the pulp slurry because the properties of wastepaper may vary significantly.

Because the foams are stabilized by surfactant only on the top of the flotation cell, it is interest to develop a feasible method to directly add the frother to the top of the flotation cell rather than in the pulp suspension. As a result, a separate control of the addition of various surfactants to improve the performance of deinking processes can be achieved.

The Mechanism of Ink Removal

Ink removal efficiency depends on several factors such as the ability to separate the ink particles from the fibers, the collision probability between ink particles and air bubbles, the interfacial energy between ink particles and the air bubble surface, the specific contact surface area between ink particles and air bubbles, the stability of the froth for final ink removal, etc. It is well-known that surface chemistry plays a key role in flotation deinking. It has also been identified that the froth stability is critical for ink removal. Ink removal efficiency increases with an increase in froth stability, so that there is an increase in surfactant concentration in conventional flotation systems. Unfortunately, the increase in surfactant concentration in the pulp suspension will increase the adsorption of surfactant onto ink particles, resulting in a reduction of the surface hydrophobicity of ink particles and ink removal [10]. Therefore, there must be an optimum surfactant concentration and ink removal efficiency. Practically, it is difficult to optimize the surfactant concentration in a paper recycle mill because of the variability in the secondary fiber sources. This indicates that a good control of surfactant concentration and its distribution within a flotation column can significantly improve the flotation deinking operation.

The Mechanisms of Fiber and Water Losses

The understanding of fiber loss in flotation is very limited. Turvey [5,6] indicated that calcium ions can significantly increase fiber loss when a fatty acid soap was used. Turvey also indicated that nonionic fatty alcohol ethoxylate surfactants cause higher fiber loss compared to fatty acid soap. It was postulated by Turvey [5,6] and later by Li and Muvundamina [15,16] that fiber loss was due to fiber adhesion to air bubbles and then was removed with the froth. This postulation was challenged by Ajersch and Pelton [7-9] and most recently by Dorris and Page [17]. They found that the hydrophobicity of a fiber surface does not contribute to fiber loss, and fiber loss is due to the mechanical entrapment of fibers in the froth. In our recent study [18], it was found that both physical entrapment of fibers in an air bubble network and adhesion of hydrophobic parts of fiber surfaces on air bubble surfaces will contribute to the total fiber loss. However, the physical entrapment is the major contributor. It was also found

that the fiber and water losses are directly related to the froth stability and froth structure. The fiber entrapment is dictated by the gravitational, buoyant, fluidynamic drag, and surface forces. In general, a froth with a structure consisting of small bubbles causes high fiber and water losses due mainly to the high void space between air bubbles for fiber and water carrying over.

Because mechanical entrapment of fiber and water in the froth is the major reason for fiber and water losses, an effective method to mechanically control the stability, structure, and fluidynamics of froth is critical for reducing fiber and water losses. It is also clear that, if other parameters remain constant, an effective mechanical control of the froth properties can be achieved by controlling surfactant concentration and distribution in the froth.

THE MECHANICAL CONTROL CONCEPT

Based on the above fundamental understandings of flotation deinking, it is clear that effective controls of key process variables can increase ink removal and reduce fiber and water losses. In this study, we propose an innovative approach to use one simple mechanical device, i.e. surfactant spray at the top of the flotation column as shown in Fig. 1, to control several key process variables, i.e., surfactant consumption, concentration and its distribution, froth structure and stability, and fluidynamics in the froth. Therefore, surfactant (frother) is not directly added into the pulp suspension during stock preparation, rather it is delivered through a spray during the flotation process. The surfactant spray concept is conceived based on the following arguments:

1. The froth that is necessary for ink removal can be established and stabilized by a surfactant spray rather than conventionally adding surfactant directly into the pulp suspension. The surfactant addition through the spray from the top of the flotation column will give a degree of freedom to control surfactant addition in flotation deinking. With this degree of freedom, we can control the froth stability through the change of surfactant concentration of the spray solution or flow rate of the spray during flotation because the froth structure and stability are related to these parameters. When a change of the fiber source is observed, the surfactant application can be easily adjusted. Because the

surfactant is only applied to the froth layer to stabilize the foam, the amount of surfactant required will be much less compared with that for conventional flotation through directly adding it into the pulp suspension.

2. The spray will have a wash effect on the froth, i.e., the momentum of the spray droplets penetrated into the froth will modify the fluidynamics within the microchannels of the froth to help the fibers or fiber flocks to overcome the lifting and the fluidynamic drag forces to flow down under the gravity. The water wash technique has been applied to mineral flotation processes [19-21] to increase mineral flotation selectivity. The effect of water drainage in the froth phase on the fiber loss was also studied [18]. Because the hydrophobic ink particles have stronger affinity to the air bubbles than fibers, the liquid drainage in the froth microchannels may move hydrophilic fibers more effectively than hydrophobic ink particles. Therefore, it can reduce fiber and water losses but does not significantly affect the ink removal efficiency.
3. For flotation processes that do not require collectors or dispersants, surfactant spray can control the distribution of surfactant in a flotation column so that surfactant will be concentrated in the top layer of the froth and will not be present in the pulp suspension. There is a strong surfactant concentration gradient in the region of the froth and pulp suspension interface, and the concentration gradient is supported by the froth liquid holdup capacity and the bulk convective flow of the pulp suspension driven by motions of the air bubbles. Therefore, the hydrophobicity of ink particles will not be affected, and the ink removal efficiency can be increased, or more specifically, the surfactant consumption will be significantly reduced under the same ink removal efficiency. Moreover, the contamination of fibers by surfactant can perhaps also be completely avoided using the surfactant spray approach. Furthermore, the so-called optimum ink removal surfactant concentration observed by Eppe et al., [10] and the present study in conventional flotation deinking systems does not exist, easing process control for ink removal.
4. There are significant engineering and economical advantage of using a surfactant spray to control flotation deinking: the spray is a very simple

mechanical device; it is very easy to implement a feedback control mechanism using a surfactant spray for industrial applications without significant modifications to existing conventional flotation equipment; and it can control most of the key process variables in flotation deinking.

EXPERIMENTAL

A laboratory batch-type deinking column is used to conduct the feasibility of the proposed mechanical control concept using surfactant spray. As shown in Fig. 1., the deinking column has an inner diameter of 10.16 cm. The height of the flotation cell is 86 cm, and the volume of the pulp slurry for each batch run is 6 liters. A pressure spray nozzle is mounted at the top of the deinking column approximately 2 cm above the pulp suspension surface to the spray surfactant. The nozzle orifice diameter is about 0.46 mm. The nozzle is operated at a gauge pressure of 0.5 atm with a flow rate of 1.42 g/s. The mean spray droplet size Sauter mean diameter (SMD) is about 50 μ m measured by a laser diffraction instrument (Malvern 2600). The flotation air flow rate is 11-15 SLPM.

The pulp was made from xerox copied bond papers printed with a fixed pattern. The papers were pulped at a pH of 10 at a consistency of 8% without adding any chemicals except sodium hydroxide. The water and fiber losses were obtained by a gravimetric method. The ash contents in the original pulp and removed solid were 16 and 8.2%, respectively. The pulp consistency used in the flotation process was 0.5%. Triton-100 (analyze grade, J.T. Backer Inc.) was used as surfactant. The required amount of Triton-100 was added directly into the pulp in "conventional flotation", but was sprayed through a nozzle from the top of the pulp in "surfactant spray flotation". The equilibrium time for surfactant adsorption in "conventional flotation" was ~5 minutes. The handsheets for brightness analysis were made on a 15-cm Büchner funnel according to TAPPI standard method. The brightness of the handsheets was measured using a Shimadzu UV-VIS spectrophotometer (UV-160A).

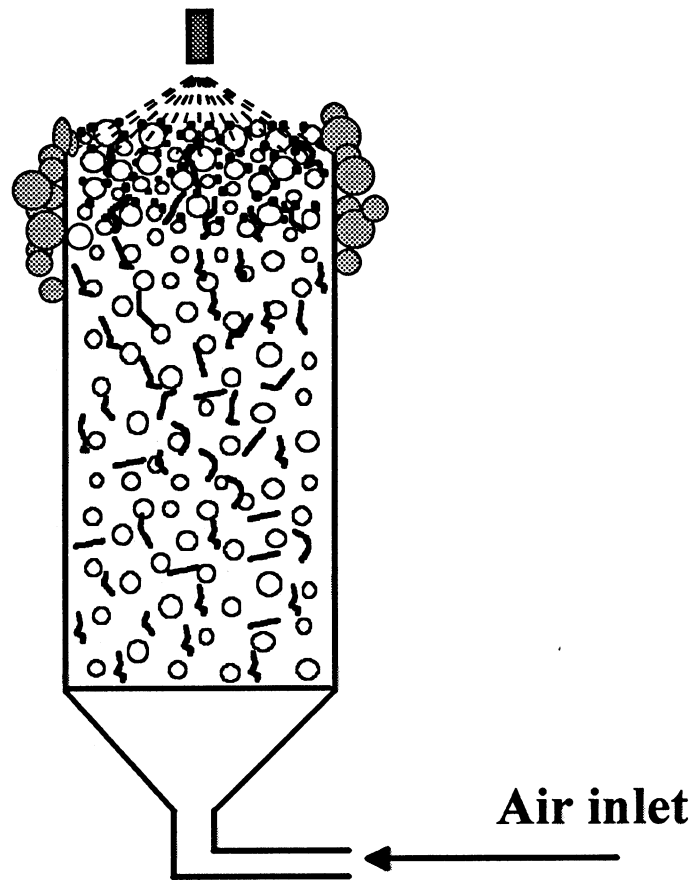


Fig. 1. Schematic diagram of a batch-type flotation deinking cell with mechanically controlled surfactant addition through a pressure atomizer.

The surfactant diffusion in the flotation column was analyzed by the concentration change as a function of time and depth along the flotation cell. The surfactant diffusion in the flotation cell was only conducted in the absence of fibers. The concentration of the surfactant (TX-100) was measured using a Shinazu UV160U spectrophotometer at a wavelength of 223 nm. Deionized water was used as a reference.

RESULTS AND DISCUSSION

Froth Establishment by Surfactant Sprays

The froth formation under the application of surfactant spray from the top of a flotation column was first examined in the absence of fibers. No foam layer was established when air bubbles were injected from the bottom of the flotation column that contains only pure water. However, when a small amount of Triton-100 solution was sprayed from the top of the flotation cell, a stable foam layer was established on the surface of the pure water phase in less than 0.5 minutes. The rate of foam formation on the top of pure water depends on the spray rate and surfactant concentration of the spray solution, and usually a few seconds are needed to generate a constant froth height.

Surfactant Distribution between Froth and Pulp Suspension

Direct sampling measurements of the surfactant concentration distribution within the flotation column as a function of spray time and depth from froth/suspension interface were conducted. It was found that surfactant is mainly concentrated in the froth rather than in the pulp suspension, and there is a strong surfactant concentration gradient in the region of the froth and pulp suspension interface. The first set of experiments was conducted by taking samples from 20 and 50 cm down from the froth and pulp suspension interface at various times up to 13 minutes during flotation with surfactant spray. UV analysis of all the samples found no absorbance at 223 nm, indicating the surfactant concentration was essentially zero at these two locations. The similar results were obtained from analysis of the samples taken from different depth (1 cm to 50 cm down from the froth/pulp suspension interface) at the end of flotation (10 minute flotation time), i.e., no detectable surfactant was found in the flotation cell.

These results strongly suggest that fiber contamination and surfactant adsorption onto the ink particle surface can be completely eliminated using the proposed surfactant spray approach in flotation deinking.

Comparisons of Ink Removal

Fig. 2 shows the comparison of the brightness gain of handsheets made from deinked fibers using surfactant spray flotation and conventional flotation under the same operation conditions, respectively. The results clearly show that the surfactant consumption used in the surfactant spray flotation is only about 2-3% of that required for the conventional flotation process in order to achieve the same brightness gain. This is not surprising because the surfactant is applied directly to the froth phase to stabilize the foam in the surfactant spray flotation, but most surfactants dissolved in pulp in the conventional flotation process will not contribute to froth stabilization. Theoretically, the surfactant consumption used in the spray flotation process can be further decreased if the ratio of the height of the flotation column to the surface area is increased because the surfactant consumption in spraying flotation is independent of the total volume, but is only dependent on the total surface area of the pulp suspension.

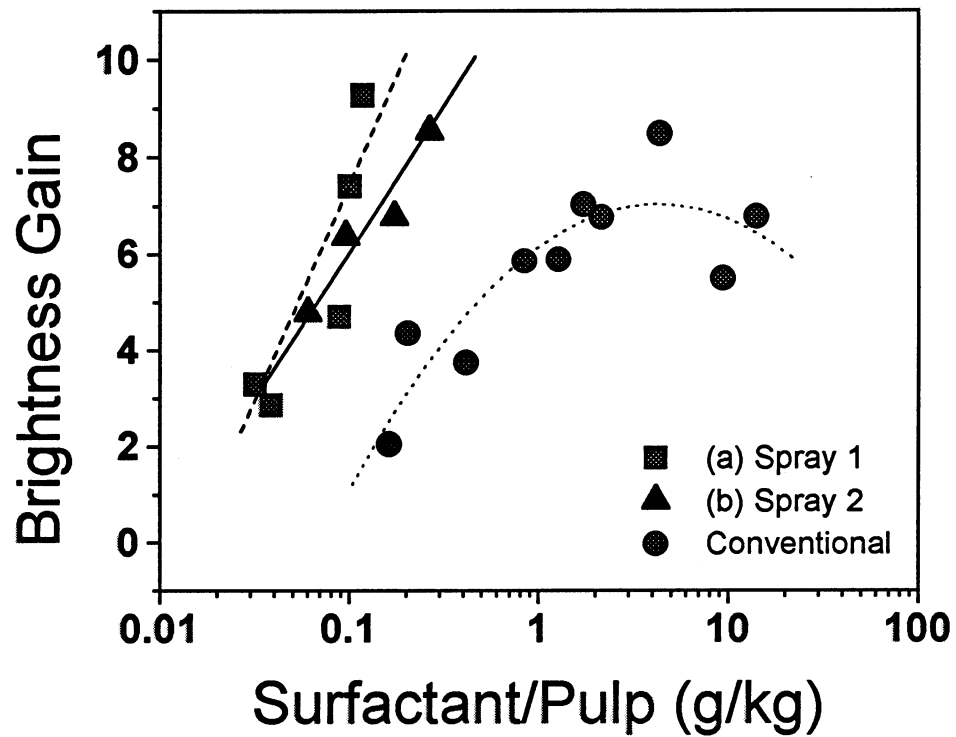


Fig. 2. Froth height vs. time with surfactant spray at different surfactant solutions in the spray solution. The surfactant concentrations in the spray solutions were 16 and 40 mg/L for Spray 1 and Spray 2, respectively. Flotation time was 10 minutes.

It can be seen from Fig. 2 that, for conventional flotation, the deinking efficiency increases with surfactant concentrations up to 5 g/kg dry pulp, then decreases suddenly as the surfactant concentration is further increased. An optimum surfactant concentration in flotation deinking was also observed in previous studies [10,11,18]. Combining present results with that of previous studies, it is believed that the increase in deinking efficiency at low surfactant concentration is because of the increase in the froth stability, and the decrease in deinking efficiency at high surfactant concentration is because of the decrease in the hydrophobicity of ink particle surfaces. Because there is an optimum surfactant concentration in conventional flotation deinking, it is often difficult to control surfactant concentration in industrial applications as it often changes with fiber sources. In contrast to the conventional flotation method, it is not necessary to find an optimum surfactant concentration if the surfactant is added from the top of the flotation cell as indicated by the data shown in Fig. 2.

Comparisons of Fiber and Water Losses

Fig. 3 plots the correlation of fiber loss as a function of brightness gain. The results show that fiber loss was reduced by 50% when surfactant is sprayed from the top of the flotation column compared to that obtained using conventional technology at the maximum ink removal condition. This indicated the success of the proposed technology in reducing fiber loss without reducing the deinking efficiency. The reduction in fiber loss, perhaps, can be attributed to the froth structure that affects the fiber drainage and spray washing that modifies the fluidynamics within the microchannels of the froth. The results

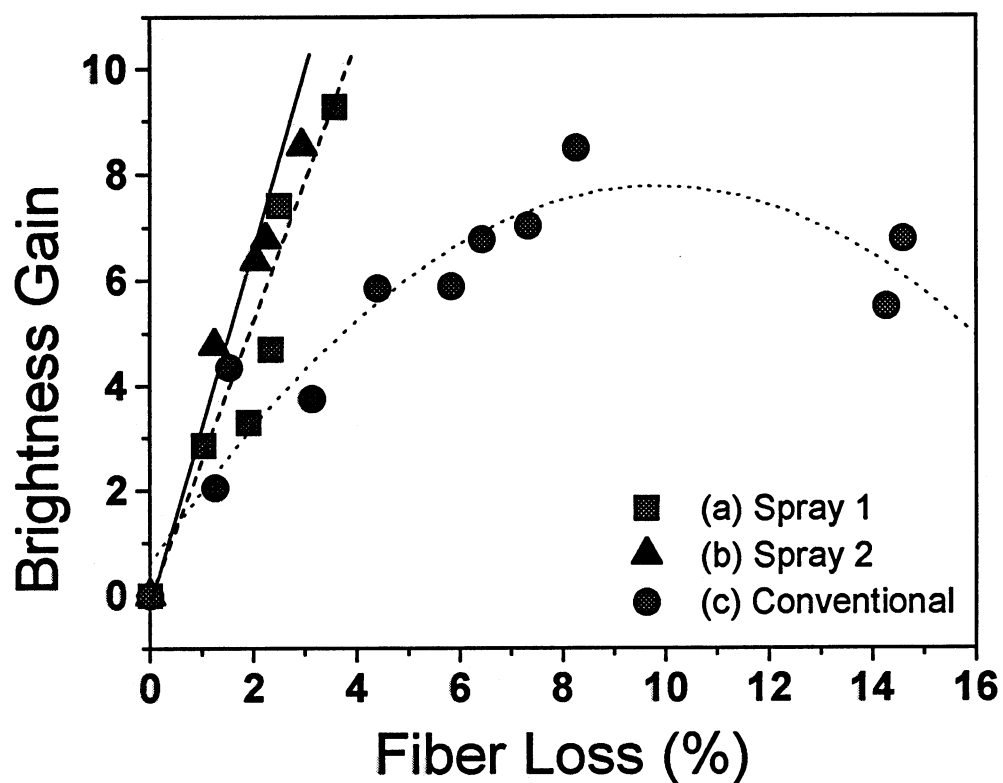


Fig. 3. The comparison of the correlation of fiber loss and deinking efficiency between the surfactant spray flotation and the conventional technology. The surfactant concentrations in the spray solutions were 16 and 40 mg/L for Spray 1 and Spray 2, respectively. Fiber loss was measured at different surfactant additions. Flotation time was 10 minutes.

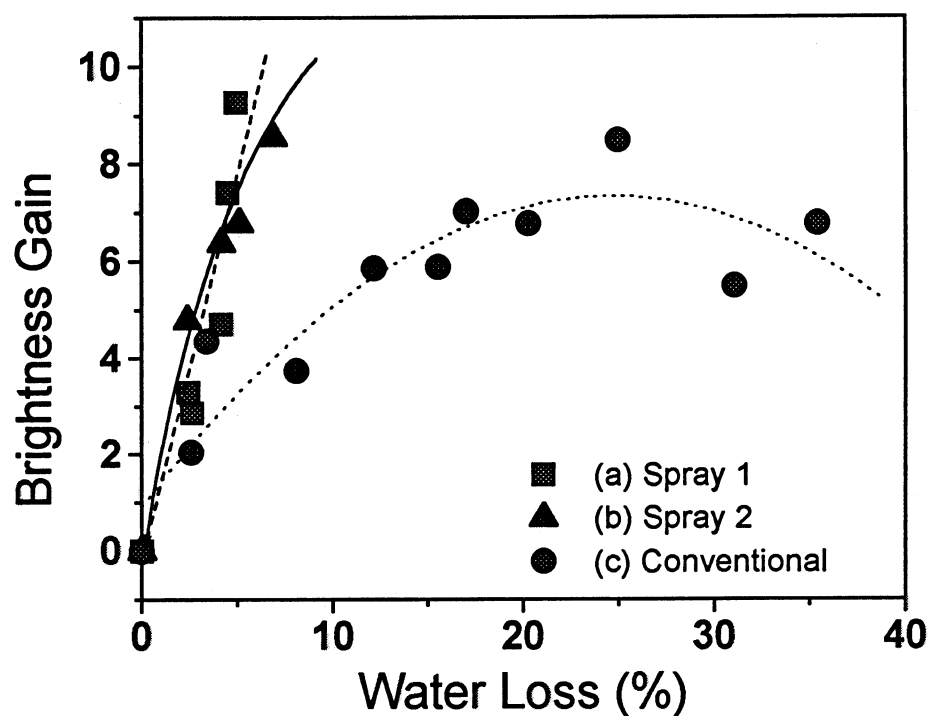


Fig. 4. The comparison of the correlation of water loss and deinking efficiency between the surfactant spray floatation and the conventional technology. The surfactant concentrations in spray solutions were 16 and 40 mg/L for Spray 1 and Spray 2, respectively. Water loss was measured at different surfactant additions. Flotation time was 10 minutes.

obtained in mineral flotation [19-23] support this explanation. However, a quantitative study of the relationship between fiber loss and froth structure is required.

Fig. 4 plots the correlation of water loss with brightness gain. The results show that the water loss was reduced by 75% when surfactant was sprayed using the proposed approach compared to that with the conventional flotation process at the maximum ink removal conditions. This indicated the success of the proposed technology in reducing water loss without reducing deinking efficiency. The reduction of water loss can be explained as that for fiber loss. According to our recent survey, water loss caused by froth entrainment in flotation deinking is about 10 tons/ton dry paper. Although the water loss caused by froth entrainment in the flotation deinking process has not been considered a serious problem, it is believed that this issue will attract more and more attention as environmental consideration increases.

Comparison of Ink Removal Rates

Fig. 5 shows the time-dependent characteristics of ink removal in the surfactant spray flotation and the conventional flotation processes. Ink removal increases as an initial increase in flotation time for all of the four experiments conducted. However, for the conventional flotation conducted at a surfactant concentration of 2 mg/L, ink removal efficiency reached a constant value after 80 seconds. A constant ink removal is solely because there was not enough surfactant in the system after 80 seconds so that the foam was not stable. The results in Fig. 5 also indicate that the ink removal rate using the proposed innovative technology is compatible with that of the conventional technology even though the surfactant consumption was reduced more than 95%.

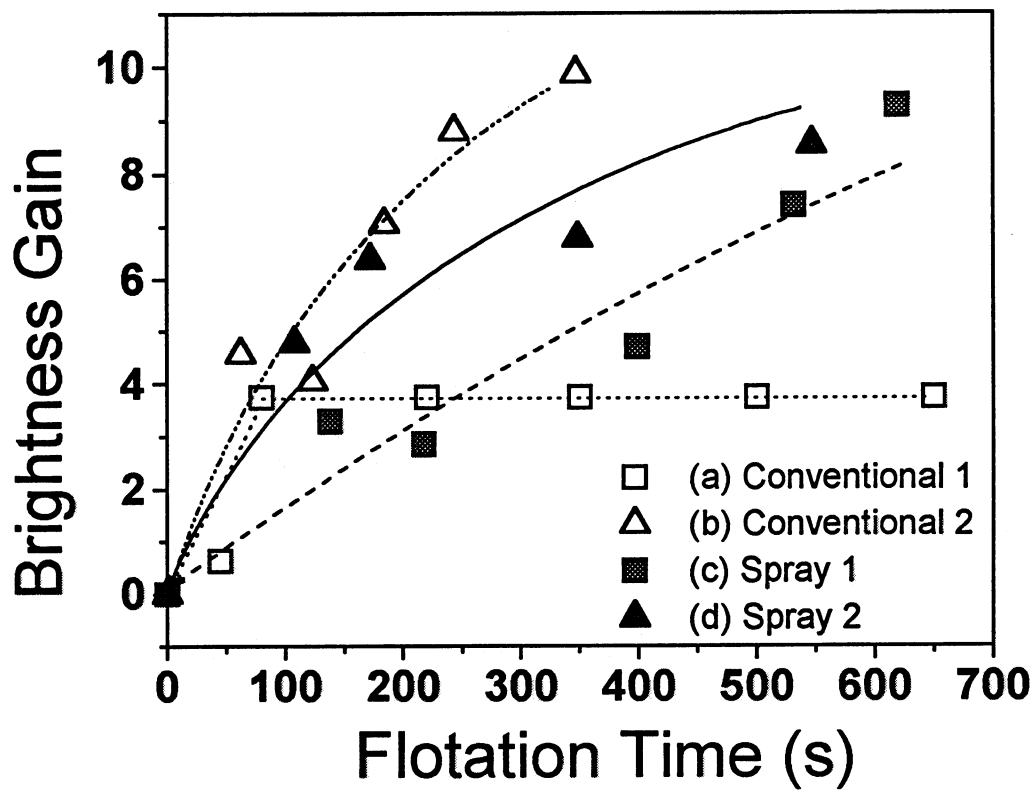


Fig. 5. Comparison of the time-dependent deinking characteristics between the surfactant spray flotation and the conventional technology. The surfactant concentrations in the spray solutions were 16 and 40 mg/L for Spray 1 and Spray 2, respectively. The surfactant concentrations in Conventional 1 and Conventional 2 were 2 and 20 mg/L, respectively.

CONCLUSIONS

In summary, the proposed approach of applying process control in flotation deinking using surfactant spray demonstrates several advantages compared with the conventional flotation deinking process:

1. Spray surfactant at the top of the flotation column can effectively establish a stable froth for good ink removal.
2. Surfactant application through a spray at the top of the column can effectively prevent the fiber from surfactant contamination, and reduce the modification of deinking chemistry through surfactant adsorption, resulting in higher ink removal, lower surfactant consumption, and lower fiber and water losses.
3. Control of surfactant delivery through mechanical devices, such as a spray, is an excellent approach to control froth stability and to improve the performance of the flotation deinking process significantly.
4. Control of surfactant delivery is a potential effective method to improve the roles of dispersant, collector, and frother in flotation deinking.
5. Control of surfactant delivery has potential advantages in whole process control in flotation deinking, and particularly can be used for stabilizing flotation operations when pulp sources are changed.
6. Laboratory studies demonstrate that without sacrificing deinking efficiency, the proposed approach can reduce fiber loss by 50%, water loss by 75%, and surfactant consumption by 95%.

OBJECTIVES FOR THE NEXT SIX MONTHS

Because the funding is available for only one year (9/97 - 8/98), the objectives given here are based on the study that will be conducted in the next six months.

1. Demonstrate the proposed technology in a pilot scale flotation facility using office wastepaper.

2. Perform a feasibility study for ONP papers using the novel surfactant spray technique.

DELIVERABLES

1. Final report will be sent to the member companies in September 1998.
2. If promise results are obtained from a continue flow flotation cell, we will contact recycling mills and equipment manufacture to transfer our results.

SCHEDULE IN MONTH

Tasks	1	2	3	4	5	6
1. Install a continue flotation cell	X	X	X			
2. Demonstrate the proposed technology in a pilot scale flotation facility using office wastepaper.				X	X	X
3. Perform a feasibility study for ONP papers using the novel surfactant spray technique.				X	X	X

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